United States Patent Application

of

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for

SELF-ORGANIZING WIRELESS NETWORKS WITH MULTIPLE TRANSCEIVERS

SELF-ORGANIZING WIRELESS NETWORKS WITH MULTIPLE

TRANSCEIVERS

BACKGROUND OF THE INVENTION

Cross Reference to Related Applications

[001]   The instant patent application is related to co-pending U.S. Patent Application Serial No. 09/513,757, entitled "A NODE BELONGING TO MULTIPLE CLUSTERS IN AN AD-HOC WIRELESS NETWORK", filed February 25, 2000; U.S. Patent Application Serial No. 09/584,973, entitled "METHOD AND APPARATUS FOR VARYING THE RATE AT WHICH BROADCAST BEACONS ARE TRANSMITTED", filed June 1, 2000; U.S. Patent Application Serial No. 09/624,635, entitled "CLUSTER HEAD RESIGNATION TO IMPROVE ROUTING IN MOBILE COMMUNICATION SYSTEMS", filed July 24, 2000; U.S. Patent Application Serial No. 09/660,521, entitled "USING DIRECT CLUSTER MEMBER TO CLUSTER MEMBER COMMUNICATION TO IMPROVE PERFORMANCE IN MOBILE COMMUNICATION SYSTEMS," filed September 12, 2000; and U.S. Patent No. 5,850,592, entitled "METHOD FOR SELF-ORGANIZING MOBILE WIRELESS STATION NETWORK", filed January 11, 1996 as U.S. Patent Application Serial No. 09/584,492, and issued December 15, 1998, all being incorporated herein by reference in their entirety.

Field of the Invention

[002]   The present invention relates to wireless data communication networks and more

particularly to such a network that employs mobile wireless terminals and that automatically

organizes itself for efficient operation.

Description of Related Art

[003]   Wireless data communications networks may be constructed where a number of (possibly

mobile) stations will automatically organize themselves into a hierarchical network. The

hierarchical network may contain one or more clusters of stations, each cluster having one cluster

head and zero or more cluster members. The cluster heads may operate at a relatively high power

level to provide longer distance network links, also known as backbone links, for the network.

The cluster members may operate at a lower power in the same frequency band to communicate

with the cluster heads. Such self-organizing, or ad-hoc, networks may adaptively reorganize in

the face of movement or destruction of cluster heads.

[004]   Fig. 1 illustrates a communications network 100 that employs a plurality of similar

(possibly mobile) stations, some of which operate as cluster heads 110. The cluster heads 110

may be interconnected by one or more backbone links 115. Each cluster head 110 defines a

cluster, and the cluster may include zero or more cluster members 120. The cluster members 120

communicate directly with the cluster heads 110 through communication links. The dashed line

130 illustrates one such cluster, containing cluster head 110 and two cluster members 120.

[005]   The cluster heads 110 and the cluster members 120 may be similar in construction, for

example a single model of radio that may transmit at different signal powers. In the exemplary

network 100, each station 110/120 may transmit at either a relatively high power level that is

suitable for relatively long network links (e.g., cluster heads 110) or at a relatively low power

level that is suitable for relatively long or relatively short network links (e.g., cluster members

120). Likewise, each station 110/120 may operate in at least two basic modes. One of the modes

(e.g., for cluster heads 110) may be as a "backbone radio" for providing message transit between

a number of cluster members and another cluster head. The other mode (e.g., for cluster

members 120) may be as a "cluster radio" for providing relatively local message access to the

cluster head 110 or to other cluster members 120. The cluster head stations operate at the

relatively high power level to communicate with other cluster head stations, and thereby form

network backbone 115.

[006]   Each station 110/120 has both transmitting and receiving capabilities (i.e. operates as a

transceiver). The network 100 may, for example, be operated as a packet switched digital data

network for communicating messages from one station to another once its configuration is

established. As is understood by those skilled in the art, procedures exist for routing messages

over a network, even when the configuration of the network may occasionally change. Likewise,

there are procedures for measuring or rating the connectivity of a network in particular

configurations.

[007]   Though Fig. 1 illustrates a particular interconnection of the various stations 110/120

shown, it should be understood that other patterns of connections are possible. Further, the

pattern of connections can change during operation, both to accommodate the introduction of

new stations and to allow for the withdrawal or movement of one of the existing stations. The

mode of operation of each station may be controlled by an embedded microprocessor in accordance with known network self-organization and communication algorithms.

[008] Using a similar station for both cluster heads 110 and cluster members 120 may result in the overall system 100 being too expensive. For example, if the majority of the stations become configured as cluster members 120, the added functionality for becoming cluster heads in these stations may increase the per-station cost over, for example, dedicated cluster member stations. Further, if both cluster heads 110 and cluster members 120 utilize the same wireless channel, system throughput may suffer. Also, networks that use a single type of transceiver necessarily are limited in future expandability (i.e., incorporating new or different transceivers within the network). Thus, systems with a single transceiver may not be able to employ a mixture of microwave and VHF radio links in a single network, nor a mixture of acoustic and radio links, nor a mixture of infrared broadcast and laser links, etc.

[009] Accordingly, there exists a need for self-organizing communication networks that avoid the shortfalls of such networks that utilize only one type of transceiver for both cluster heads and cluster members.

SUMMARY OF THE INVENTION

[0010] Systems and methods, consistent with principles of the invention, address this and other needs by providing multiple transceivers within a wireless terminal. Thus, a terminal may contain one or more backbone transceivers and one or more cluster transceivers to allow the terminal to communicate with other terminals that may contain different types of transceivers.

[0011] In accordance with the purpose of the invention as embodied and broadly described herein, a method for integrating a wireless terminal into a wireless network includes determining whether the wireless terminal contains one or more functioning cluster transceivers, and attempting to affiliate the wireless terminal with a cluster head as a cluster member if the wireless terminal contains one or more functioning cluster transceivers. The wireless terminal may operate as a cluster head if the wireless terminal does not contain one or more functioning cluster transceivers.

[0012] In another implementation consistent with principles of the invention, a method for configuring a wireless terminal within a wireless network includes operating the wireless terminal as a cluster head, and determining whether a cluster defined by the wireless terminal contains one or more functioning cluster radios. The terminal continues to operate as a cluster head if the cluster contains no functioning cluster radios. The method may also ascertain whether continued operation of the wireless terminal as a cluster head is necessary if the cluster contains one or more functioning cluster radios. The terminal may attempt to resign as the cluster head if the continued operation of the wireless terminal as a cluster head is not necessary.

[0013] In a further implementation consistent with principles of the invention, a wireless network includes a group of first wireless terminals configured to operate as cluster heads by communicating with at least one other cluster head over one or more backbone links. Each of the first wireless terminals includes one or more backbone transceivers. At least one second wireless terminal is configured to operate as a cluster member by communicating with an associated cluster head over one or more local links. Each of the second wireless terminals includes one or

more cluster transceivers. At least one of the first and second wireless terminals includes both a

backbone transceiver and a cluster transceiver.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The accompanying drawings, which are incorporated in and constitute a part of this

specification, illustrate an embodiment of the invention and, together with the description,

explain the invention. In the drawings,

[0015] Fig. 1 is a diagram illustrating a self-organizing wireless communications network;

[0016] Fig. 2 is a schematic diagram illustrating a wireless terminal that includes multiple

transceivers in accordance with an implementation consistent with the present invention;

[0017] Fig. 3 is a schematic diagram illustrating a wireless terminal that includes multiple

transceivers and cryptographic capability in accordance with another implementation consistent

with the present invention;

[0018] Fig. 4 is a schematic diagram illustrating a wireless terminal that includes multiple

transceivers, cryptographic capability, and multiple routers in accordance with another

implementation consistent with the present invention;

[0019] Fig. 5 is a flowchart of exemplary processing by a wireless terminal according to an

implementation consistent with principles of the invention;

[0020] Fig. 6 is a flowchart illustrating in greater detail an affiliation procedure employed in the

flowchart of Fig. 5;

[0021] Fig. 7 is a flowchart illustrating in greater detail an affiliation check procedure employed

in the flowchart of Fig. 5;

[0022] Fig. 8 is a flowchart illustrating in greater detail a resignation procedure employed in the flowchart of Fig. 5;

[0023] Fig. 9 is a flowchart illustrating a resignation check procedure performed by cluster heads upon receipt of a resignation request message sent in Fig. 8; and

[0024] Fig. 10 is a flowchart illustrating a resignation check procedure performed by cluster members upon receipt of the resignation request message sent in Fig. 8.

DETAILED DESCRIPTION

[0025] The following detailed description of the invention refers to the accompanying drawings. The same reference numbers in different drawings identify the same or similar elements. Also, the following detailed description does not limit the invention. Instead, the scope of the invention is defined by the appended claims and equivalents.

[0026] Systems and methods, consistent with the principles of the invention, provide a self-organizing wireless network including a number of wireless terminals. Each wireless terminal may include a number of different transceivers (e.g., radios), including one or more cluster radios to enable the terminal to function as a cluster member and/or one or more backbone radios to enable the terminal to function as a cluster head. Cluster radios and backbone radios may be different types of radios that operate in different frequency bands. Preferably, a terminal will contain at least one cluster radio and at least one backbone radio, but a terminal may also contain only one radio, either of cluster or backbone type.

EXEMPLARY WIRELESS TERMINAL CONFIGURATION

[0027] Fig. 2 is a schematic diagram illustrating a wireless terminal 200 that includes multiple

transceivers in accordance with an implementation consistent with the present invention.

Wireless terminal 200 may include a router 210, a network interface device 220, three wireless

transceivers 230-250, a combiner 260, and two antennas 235/265. The wireless terminal 200

may also include one or more input devices such as a keyboard, stylus, etc. (not shown) and one

or more output devices such as a display screen (not shown). The wireless terminal 200 may be

either stationary or mobile (e.g., mounted on a vehicle or carried by a person).

[0028] The router 210 may include a processor (not shown) configured to execute wireless

networking algorithms. The processor in router 210 may include a general purpose processor,

one or more application-specific integrated circuits (ASICs), field programmable gate arrays

(FPGAs), digital signal processors (DSPs), etc. The processor in router 210 may host software

such as an internet protocol (IP) routing routine, network management functions, application

programs, etc. Router 210 may be connected to and may communicate with other components of

the wireless terminal 200 via a system bus.

[0029] Network interface device 220 may include, for example, an Ethernet hardware card and

its associated controller. The device 220 may include other types of interface hardware that

provides a physical connector with which to interface with an external network.

[0030] Wireless transceivers 230-250 may include any type of wireless transceiver, including

radio frequency (RF), acoustic, infrared, or microwave transceivers. Other types of transceivers

that may send and receive signals are possible. For ease of reference, these transceivers may be

referred to as "radios." The transceivers 230-250 may also include components such as

processors, DSPs, ASICs, or special RF equipment. Although antenna 235 has been illustrated

as a radio antenna devoted to transceiver (e.g., radio) 230, it should be understood that antenna

235, and the other antenna(s) shown, may include acoustic speakers and/or microphones, infrared

transmitters and/or detectors, or any other type of transmitter or detector that is appropriate for a

transceiver in the wireless terminal 200. The transceivers 230-250 may be of different types

(e.g., different frequency bands and/or different access protocols).

[0031] In the implementation shown in Fig. 2, the combiner 260 may combine signals to or from

transceivers 240 and 250. In this manner, transceivers 240 and 250 may share the antenna 265.

However, it should be noted that the present invention is not limited solely to the implementation

shown in Fig. 2. For example, another implementation could contain three distinct acoustical

transceivers that share a common receiver (e.g., microphone), but that each has its own

transmitter (e.g., speaker). Thus, the arrangement shown in Fig. 2 is but one of many possible

permutations, and fewer transceivers (e.g., one) or more transceivers (e.g., five or more) are

possible within a single wireless terminal. Further, although discrete transceivers 230-250 are

shown, those skilled in the art will appreciate that such transceivers may all be implemented by,

for example, a single frequency-agile radio that is capable of operation in different bands and

with different modulations.

[0032] Depending on the number and type of transceivers in the terminal 200, it may be capable

of functioning as either a cluster head 110 or a cluster member 120. For example, the

communications network 100 may employ one type of radio (e.g., a relatively high-powered

radio operating in the ultra-high frequency (UHF) band, an optical laser transceiver, a microwave

transceiver, or a code division multiple access (CDMA) radio) as a backbone radio, and several

types of radios (e.g., those conforming to the IEEE 802.11 standard operating at 2.4 GHz, an

acoustic transceiver, an omni-directional optical (e.g., infrared) transceiver, a very high frequency

(VHF) transceiver, a cellular-telephone-based transceiver, a CDMA radio, an ultra-wideband

(UWB) radio, or a time-division multiple access (TDMA) radio) as cluster radios. The terminal

200 may contain both "backbone" and "cluster" radios, in which case it may function as either a

cluster head 110 or a cluster member 120. Exemplary terminal configurations may include one

backbone radio and one cluster radio, multiple backbone radios and no cluster radios, multiple

cluster radios and no backbone radios, one backbone radio and multiple cluster radios, or

multiple backbone radios and multiple cluster radios. However, the terminal may contain only

one or more "backbone" radios or only one or more "cluster" radios, in which case it may

function only as a cluster head 110 or only as a cluster member 120.

[0033] Fig. 3 is a schematic diagram illustrating a wireless terminal 300 that includes multiple

transceivers and cryptographic capability in accordance with another implementation consistent

with the present invention. Wireless terminal 300 includes all elements 210-265 of the terminal

200 in Fig. 2, and these elements will not be described again. Wireless terminal 300 also

includes a crypto block 310, a red bus 320 connected between crypto block 310 and router 210,

and a black bus 330 connected between crypto block 310 and transceivers 230-250.

[0034] Crypto block 310 is configured to scramble/encode data passing from the red bus 320 to

the black bus 330, and to descramble/decode data passing from the black bus 330 to the red bus

320. Crypto block 310 may include hardware or software-implemented encryption capability.

Those skilled in the wireless data transmission art will make appropriate algorithm trade-offs

between, for example, encryption speed and encryption strength. The presence of crypto block

310 allows messages to be scrambled/encoded when they pass among various cluster heads 110

and cluster members 120 in the wireless network 100.

[0035] Fig. 4 is a schematic diagram illustrating a wireless terminal 400 that includes multiple

transceivers, cryptographic capability, and multiple routers in accordance with another

implementation consistent with the present invention. Wireless terminal 400 includes all

elements 210-250 and 310-330 of the terminal 300 in Fig. 3 (with the exception of combiner

260), and these elements will not be described again. In Fig. 4, transceivers 240 and 250 each

have dedicated antennas 245 and 255, which allows for operation over different frequency bands.

Wireless terminal 400 also includes a black router 410 connected to the black bus 330.

[0036] Black router 410 may include a processor (not shown) configured to execute wireless

networking algorithms among devices in communication with the black bus 330. The processor

in black router 410 may include a general purpose processor, one or more ASICs, FPGAs, DSPs,

etc. The processor in black router 410 may host software such as an internet protocol (IP)

routing routine, network management functions, application programs, etc. Router 410 may

communicate with transceivers 230-250 and any connected devices to route scrambled messages,

but is isolated from the red bus 320 by the crypto block 310. Isolating the black router 410 in

such a manner provides extra security for the red bus 320 which may be connected to devices

containing sensitive information by the network interface device 220.

EXEMPLARY WIRELESS TERMINAL PROCESSING

[0037] Fig. 5 is a flowchart of exemplary processing by a wireless terminal according to an

implementation consistent with principles of the invention. The processing in Fig. 5 applies

equally to any of wireless terminals 200-400 to effect the automatic organization of terminals

into a communication network 100. Certain of the acts in the flowchart are described initially

only in general functional terms and are later described in greater detail in other figures.

[0038] After a wireless terminal is initially activated, a delay of random duration, but within

preselected bounds, is provided [act 510]. This random delay also may be introduced by several

other acts in the flowchart and is influential in implementing the general and fair allocation of

functions (e.g., cluster head, cluster member) to the various terminals.

[0039] After the random delay, the terminal checks whether it contains any functioning cluster

radios [act 515]. If the terminal does not contain any functioning cluster radios, the terminal

begins operation as a cluster head [act 530]. This ensures that a terminal without any cluster

radios will immediately become a cluster head.

[0040] If the terminal contains at least one functioning cluster radio, the terminal executes an

affiliation procedure [act 520]. During the affiliation procedure, the terminal attempts to affiliate

with an existing cluster head terminal. This affiliation procedure is described in greater detail

with reference to Fig 6.

[0041] Fig. 6 is a flowchart illustrating in greater detail the affiliation procedure 520 employed in

the flowchart of Fig. 5. The procedure begins with the candidate terminal, possibly after a delay

period T, collecting beacons (i.e., messages from head terminals that establish the head terminals'

presence and availability) from all cluster head terminals within range [act 610]. The terminal

performs such collection for each type of cluster radio within the terminal. The candidate

terminal may collect beacons on each of its cluster radios for some period of time. The terminal

in question may also establish one or more lists of such beacons, depending on the number of

cluster radios it contains. The terminal may ignore head terminals with beacon signal strengths

below a pre-selected threshold [act 620]. A separate threshold may be used for each type of

cluster radio within the terminal.

[0042] The terminal then checks whether any cluster head terminals remain on its list after those

with low signal strength are ignored [act 625]. If no head terminals remain on the list after

removing those with low signal strengths, the affiliation procedure 520 is terminated as

unsuccessful [act 630]. This is equivalent to a NO result from act 525 in Fig. 5. If, however, at

least one head terminal remains on the list after removing those with low signal strengths, the

available head terminals are ordered in a list progressing from the most preferred (e.g., that most

matches a given criteria) to the least [act 640]. The ordering should take into account which type

of radio within the terminal (e.g., among radios 230-250) is more "desirable" to use. Desirability

of radio types may be determined by power consumption, reliability, ease of signal detection, etc.

[0043] As will be understood by those skilled in the art, the beacon collection and ordering

procedure in Fig. 6 alternatively may be implemented as a continuous, background operation to

maintain a "preferred list" of head terminals, because such a list is also utilized at other points in

processing in Fig. 5.

[0044] An affiliation request message may be sent to the cluster head terminal that is most preferred, (i.e., the cluster head terminal at the top of the ordered list) by the corresponding cluster radio within the candidate terminal [act 650]. If, within a predetermined time interval, a response message is received from the most preferred cluster head terminal (CH) [act 655], the candidate affiliate member sends off a message confirming its affiliation to that head terminal [act 660]. The procedure 520 then is terminated as being successful [act 670]. This is equivalent to a YES decision result from act 525 in Fig. 5.

[0045] If the candidate terminal does not receive a response message from the addressed head terminal, that cluster head is deleted from the list [act 680]. The terminal then determines whether another possible cluster head terminal exists on the list [act 685]. If no other cluster heads are present on the list, the procedure 520 is terminated as unsuccessful [act 630]. If there is another possible head terminal with which affiliation would be appropriate, an affiliation request may be sent to that head terminal [act 650].

[0046] Returning to Fig. 5, if the affiliation procedure 520 is successful the terminal begins to operate as a cluster member [act 540]. As is understood by those skilled in the art, wireless networking procedures typically include acknowledgement messages which confirm that a message transmitted has been received by the intended terminal. Thus, each terminal is able to determine on an ongoing basis if it is able to communicate through the network. The terminal periodically performs such testing [act 545], and as long as the terminal is able to communicate, it remains a cluster member [act 540]. However, if at some point the terminal determines that it is no longer able to communicate, the terminal returns to an initial activation state and executes

the random delay [act 510]. The terminal may then re-execute the affiliation procedure [act 520],

and it may affiliate with a different cluster head.

[0047] In addition, each cluster member periodically executes an affiliation check procedure [act

560]. The affiliation check procedure allows detection of the continued presence of a cluster

head for a cluster member terminal, and a relative signal strength of the cluster head. The

affiliation check procedure 560 is described in greater detail in Fig. 7.

[0048] Fig. 7 is a flowchart illustrating in greater detail the affiliation check procedure 560

employed in the flowchart of Fig. 5. Each cluster member terminal may store, in an appropriate

data structure, a number of "B" recent beacons from the cluster head with which it is affiliated

[act 710]. The data structure may include the signal strength of the various beacons received

from the cluster head. After a periodic timer fires or toggles [act 720], the terminal determines if

a predetermined fraction of the stored beacons B are of an amplitude that is above a threshold

signal strength value SS [act 730]. The threshold signal value may be empirically determined to

optimize network performance. In other words, the cluster member determines whether

communication with the current cluster head remains reliable.

[0049] If a certain fraction of the stored beacons B are of an amplitude that is below a threshold

signal strength value, the affiliation check is unsuccessful [act 740]. This is equivalent to a YES

result in the "check failed" determination [act 565]. If, however, a certain fraction of the stored

beacons B are of an amplitude that is above the threshold signal strength value, the affiliation

check is successful [act 750]. This is equivalent to a NO result in the "check failed"

determination [act 565]. In such an event, the terminal may continue to periodically check the

affiliation [act 560].

[0050] Returning to Fig. 5, as long as the affiliation check is satisfactory, the terminal remains as

a cluster member with its pre-existing affiliation [acts 560/565]. If such an affiliation check fails,

the terminal returns to an initial activation state and executes the random delay [act 510]. The

terminal may then re-execute the affiliation procedure [act 520], and it may affiliate with a

different cluster head.

[0051] Returning to act 525, if the affiliation procedure fails, the terminal checks whether it

contains any functioning backbone radios [act 527]. If the terminal does not contain any

functioning backbone radios, the affiliation procedure is re-executed [act 520]. If, however, the

terminal contains at least one functioning backbone radio, the terminal begins to operate as a

cluster head [act 530]. This ensures that a terminal without a backbone radio will repeatedly

attempt to become a cluster member, and will never attempt to become a cluster head.

[0052] As indicated previously, one function performed by each cluster head is to periodically

broadcast beacon messages from each of its functioning cluster radios, the beacon messages

establishing the cluster head's presence and its availability to operate as a head for other cluster

terminals. The beacon messages may be identical across different cluster radios, or may differ

based on, for example, recently observed statistics for the different cluster radios. Further, each

backbone radio in a cluster head terminal may periodically transmit messages, at least to the

other head terminals, which identify at least the members that are affiliated with that head [act

530]. Thus, the cluster head terminals may maintain a data structure indicating the present

constituency of the network and the configuration of the network backbone.

[0053] During operation, a cluster head may check whether it is associated with (i.e., is the head

of a cluster including) any functioning cluster radios [act 535]. If the cluster head does not have

any functioning cluster radios in its cluster, it continues to function as the head of a cluster [act

530]. Only if there are functioning radios in the cluster head's cluster will the cluster head

perform proximity and resignation processing. This check in act 535 ensures that a cluster head

will not attempt to resign if it has no associated cluster radios.

[0054] Periodically, each cluster head terminal tests its proximity to other cluster head terminals,

for example, by signal strength measurements or using other data available through the exchange

of messages with the cluster head terminals [act 537]. If the test indicates that proximity

conditions are exceeded (i.e., that the particular terminal's operation as a head is possibly

redundant and/or unnecessary), the terminal executes a resignation procedure [act 550]. This

resignation procedure is described in greater detail in Fig. 8.

[0055] Fig. 8 is a flowchart illustrating in greater detail the resignation procedure 550 employed

in the flowchart of Fig. 5. A terminal, presently acting as a cluster head, may broadcast a

resignation request message [act 810]. This resignation message is broadcast to all terminals

currently communicating with the cluster head that wishes to resign, namely 1) other cluster

heads, and 2) cluster members associated with the cluster head. The resignation message should

be transmitted on each type of radio within the cluster head. For example, a cluster head 200

may have two cluster radios affiliated with its radio 240 and ten cluster radios affiliated with its

radio 250. The resignation message should therefore be transmitted on both radios 240 and 250.

Assuming they receive the resignation request message, all associated cluster heads and affiliated

cluster members respectively execute procedures in response to the request. Fig. 9 illustrates the

procedure performed by the cluster heads upon receipt of the resignation request message, and

Fig. 10 illustrates the procedure performed by the cluster members upon receipt of the

resignation request message.

[0056] Fig. 9 is a flowchart illustrating a resignation check procedure performed by each

connected cluster head (i.e., a "receiving" cluster head) upon receipt of the resignation request

message sent in act 810 from the cluster head seeking to resign (i.e., the "requesting" cluster

head). A receiving cluster head receives the resignation request/warning from the requesting

cluster head [act 910]. Using data that has been collected about the network's configuration, the

receiving cluster head determines whether the requesting cluster head is an articulation point in

the network backbone configuration [act 920]. As is understood by those skilled in the art, the

removal of a node at an articulation point would break the connectivity of the network backbone.

If the requesting cluster head is an articulation point, the receiving cluster head terminal does not

send a confirmation message [act 930]. Accordingly, the requesting head terminal will be

blocked from resigning by such an action. If, however, the requesting cluster head is not an

articulation point, the receiving cluster head terminal sends an appropriate confirmation message

[act 940]. The requesting cluster head may resign if all other affected terminal also confirm.

[0057] Though the resignation check illustrated in Fig. 9 inhibits resignation if backbone

connectivity would be broken (i.e., if the requesting cluster head is an articulation point), it

should be understood that there are various ways of measuring connectivity in a network. A

decision to inhibit resignation (e.g., act 930) alternatively may be based on a reduction in

connectivity level below a preselected level according to measurements made in accordance with

these known schemes.

[0058] Fig. 10 is a flowchart illustrating a resignation check procedure performed by each

connected cluster member (i.e., a "receiving" cluster member) upon receipt of the resignation

request message sent in act 810 from its requesting cluster head. If a receiving cluster member

terminal receives a resignation request, the cluster member checks whether another head terminal

is available for affiliation [act 1010]. This check is performed using the data in the list prepared

in act 640 of Fig. 6 (or from a "preferred" list if the beacon collection and ordering is being

performed as a background task). If another cluster head is available for affiliation by the

receiving cluster member, the receiving cluster member sends an appropriate confirmation

message [act 1020]. Alternately, if no cluster head is available for affiliation by the receiving

cluster member, no confirmation message is sent [act 1030]. In this manner, a receiving cluster

member may inhibit the proposed resignation.

[0059] Returning to Fig. 8, the requesting cluster head waits a predetermined length of time after

sending its resignation request [act 820]. This wait time allows the receiving cluster heads and

the receiving cluster members time to perform their respective routines as previously described in

Figs. 9 and 10. The requesting cluster head determines whether it has received resignation

confirmation messages from all neighboring cluster heads and all affiliated cluster member

terminals [act 830]. If all such cluster head and cluster member terminals have sent confirmation

messages and the messages have been received by the resigning head terminal, the resignation

procedure terminates as successful [act 840]. This is equivalent to a YES result in the "resign

success" determination [act 555] in Fig. 5. If any neighboring cluster head or affiliated cluster

member does not provide a confirming message, the procedure terminates as unsuccessful and

the terminal continues in its role as a cluster head [act 850]. This is equivalent to a NO result in

the "resign success" determination [act 555] in Fig. 5.

[0060] Although described as requiring unanimous confirmation for a resignation, the above-

described processing may alternatively require less than unanimous confirmation. For example,

if only one cluster head or cluster member does not supply a confirmation, a requesting cluster

member may still be allowed to resign. Those skilled in the art will balance loss of network or

terminal connectivity with the benefit of allowing unimpeded cluster head resignation.

[0061] Returning to Fig. 5, if the conditions for resignation are met, the terminal processing

returns to act 510 and after the random delay and checking for functioning cluster radios [act

515], again may attempt the affiliation procedure [act 530]. In this manner, assuming the

presence of a functioning cluster radio/transceiver, the terminal may commence operation as a

cluster member rather than a cluster head as before.

[0062] The foregoing description of preferred embodiments of principles of the invention

provides illustration and description, but is not intended to be exhaustive or to limit the invention

to the precise form disclosed. Modifications and variations are possible in light of the above

teachings or may be acquired from practice of the invention. For example, although a two level

network architecture has been described, it should be understood that implementations of the

invention are inherently recursive. Thus, a three or four level architecture may be implemented,

using high-level cluster heads to connect with clusters of lower-level cluster heads. In one

implementation, power levels may be increased for these high-level cluster heads. In another, the

high-level heads may comprise a different type of transceiver (e.g., microwave, etc.) than the

transceivers in the lower levels of the network.

[0063] Thus, the present invention is intended to encompass using multiple types of transceivers

(e.g., radios) among levels of the above-described network and/or within levels of the network.

For example, a network consistent with the present invention may include a different type of

radio used for the backbone links than is used for the cluster members. A network consistent

with the present invention may additionally or alternately incorporate more than one type of radio

within a particular level. That is, two or more different types of radios may be used as cluster

members. A particular cluster may incorporate only one type of radio, or may incorporate more

than one type for its cluster members. If more that one type of radio is used within a cluster, the

cluster head terminal should contain enough transceivers (e.g., more than one) to enable

communication with the different types of cluster member radios. Similarly, more than one type

of backbone radio may be utilized, as long as the affected cluster heads contain at least one type

(and preferably all types) of the backbone radios, so that connectivity among cluster head nodes

is not adversely affected.

[0064] As previously noted, the above-described terminals (e.g., in Figs. 2-4) may be stationary

terminals or mobile terminals. As used herein, the term "mobile terminal" may include a cellular

radiotelephone with or without a multi-line display; a Personal Communications System (PCS)

terminal that may combine a cellular radiotelephone with data processing, facsimile and data

communications capabilities; a PDA that can include a radiotelephone, pager, Internet/intranet

access, Web browser, organizer, calendar and/or a global positioning system (GPS) receiver; and

a conventional laptop and/or palmtop receiver or other appliance that includes a radiotelephone

transceiver. Mobile terminals may also be referred to as "pervasive computing" devices.

[0065] In addition to the implementations described above, cluster members may advantageously

communicate, not only with their cluster head, but also with other cluster members. Those

skilled in the art will appreciate how to implement such communication after studying co-

pending, commonly assigned, application serial no. 09/660,521, filed September 12, 2000,

entitled "Using Direct Cluster Member to Cluster Member Communication to Improve

Performance in Mobile Communication Systems." Also, cluster members may advantageously

communicate, not only with their associated cluster head, but also with other cluster heads.

Those skilled in the art will appreciate how to implement such communication after studying co-

pending, commonly assigned, application serial no. 09/513,757, filed February 25, 2000, entitled

"A Node Belonging to Multiple Clusters in an Ad-Hoc Wireless Network."

[0066] Further, it may be desirable to control network growth and structure by having cluster

heads resign based on other criteria than proximity to each other. Those skilled in the art will

appreciate how to implement such resignation after studying co-pending, commonly assigned,

application serial no. 09/624,635, filed July 24, 2000, entitled "Cluster Head Resignation to

Improve Routing in Mobile Communication Systems." Also, it may be desirable to control

network traffic and performance, for example, by changing the rate at which cluster heads

transmit beacon signals. Those skilled in the art will appreciate how to implement such

transmission after studying co-pending, commonly assigned, application serial no. 09/584,973,

filed June 1, 2000, entitled "Method and Apparatus for Varying the Rate at Which Broadcast

Beacons Are Transmitted."

[0067] No element, act, or instruction used in the description of the present invention should be

construed as critical or essential unless explicitly described as such. Also, as used herein, the

article "a" is intended to include one or more items. Where only one item is intended, the term

"one" or similar language is used. The scope of the invention is defined by the claims and their

equivalents.